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of microgrids as well as distributed and renewable generation devices, and the enhancement by distribution automation. In my view, the following areas are essential for the resiliency of the future distribution systems.

New Concepts and Analytical Tools for Resiliency

A standardized definition of resiliency is needed to develop the requirements and procedures for distribution system planning and operation. In the transmission area, the *N*–1 (or *N*–2) security criterion is widely adopted by industry worldwide. A power system is said to be secure if the system is able to maintain normal operating conditions following a single contingency such as a line or generator outage. A similar concept can be adopted for distribution systems, i.e., a distribution system is considered to be resilient if it is able to maintain service to critical load following an extreme event such as a severe hurricane or earthquake.

The availability (e.g., either available or damaged/unavailable) of various distribution system components needs to be assessed during and after the extreme event. Modeling and simulation tools are needed to evaluate the system's capability to maintain critical loads with the available generation, transmission, and distribution facilities. For planning purposes, these tools provide important information for enhancing the redundancy and connectivity of the distribution systems. For system operation, the tools can be used to determine the emergency actions that need to be taken to restore critical loads and services.

Resiliency of a distribution system is defined with respect to a system's ability to withstand rare and extreme events.

Microgrids and Distributed Energy Resources

Microgrids can be operated in a utility-connected mode with the neighboring distribution system or in an islanded mode in separation with the distribution system. The capacity of microgrids is increasing from a few megawatts to the higher level of 100 MW in the future. As microgrids become larger and better control capabilities are equipped, they can be viewed as "virtual feeders" of the distribution systems. In other words, microgrids can be deployed to pick up critical loads and services outside their territory. The new strategy will require both power grids and microgrids to evaluate the technical feasibility and cost benefit. Microgrids and distributed energy resources increase the redundancy of energy resources, leading to a higher capability to serve critical loads and services. The technical issues involve the feeder voltage/reactive power control as well as active and reactive power capabilities of the generation sources. There are also regulatory issues to address; for example, a microgrid is not a qualified utility company, and therefore it cannot serve customers outside its area.

It is estimated that 65 million smart meters will be installed nationwide by 2015.

Further Automation

Since 2009, the U.S. Department of Energy and the power industry have collaborated to implement about a hundred Smart Grid Investment Grant (SGIG) projects. As a result, the number of automated switches with remote monitoring and control capabilities has increased significantly. As of March, 2013, almost 8,000 automated switches have been installed through the SGIG projects. It is estimated that 65 million smart meters will be installed nationwide by 2015. These new capabilities for service restoration and the vast amount of information generated by the smart meters are highly valuable for the residency of distribution systems. A minimum set of remote-controlled switches can be derived to achieve the maximum capability to restore service in a distribution system, i.e., the concept of design for maximum restoration capability. The function of outage reporting for smart meters can enhance the identification of fault(s) in a distribution system, replacing traditional trouble call handling techniques. The flexible reconfiguration of distribution feeders under an extreme operating condition allows the load to be served by a number of electrical islands. By doing so, the propagation of disturbances can be contained. p&e

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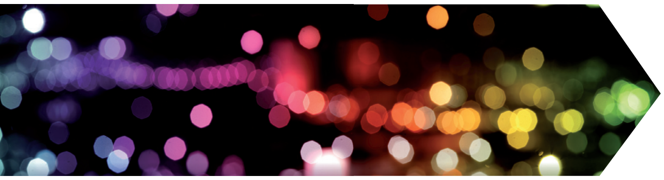

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Chen-Ching Liu

distribution systems

reliable but not resilient?

OUTAGES REGULARLY OCCUR ON distribution systems due to events such as weather, maintenance, and equipment failures. Most outages are caused by a single event, such as a short circuit fault on a feeder or failure of a piece of equipment. In a typical scenario, fault indicators identify the section of the feeder where the fault occurs. Remote-controlled (or manually operated) sectionalizing switches are used to isolate the fault, and service to customers is restored in a matter of minutes.

An extreme event is not typical, however. Hurricane Sandy, "Superstorm Sandy," swept through seven countries, causing at least 286 deaths and an estimated damage of US$68 billion. Twenty-four states in the United States were affected; thousands of homes were destroyed with millions left without power, particularly in New Jersey and New York. In the United States, about 87% of the outages affecting 50,000 or more customers since 2002 have been caused by severe weather.

The reliability of distribution systems is measured essentially by the frequency and duration of power outages. Indeed, two commonly used reliability indexes are the System Average Interruption Frequency Index (SAIFI) and the System Average Interruption Duration Index (SAIDI). Since most outage scenarios involve simple events, service restoration is straightforward and outage durations are short. In a highly automated distribution system, service restoration can be achieved by remote-controlled devices. If the outage durations are sufficiently short, say, fewer than 1–5 min, they are not included in the outages for calculating reliability indices. In other words, in a highly automated distribution system, the frequency and duration of outages will be low, and, hence, the reliability is high based on existing reliability indices.

> The reliability of distribution systems is measured essentially by the frequency and duration of power outages.

The resiliency of a distribution system is defined with respect to a system's ability to withstand rare and extreme events. As shown in Table 1, numerous components may be damaged, power sources may become unavailable, and transmission/distribution system facilities may not be ready for service restoration. In addition, the communication and remote-control capabilities may be lost, and numerous priority tasks compete for the limited availability of field crews and facilities. As a result, by existing reliability metrics, a highly reliable distribution system is not necessarily resilient. There is presently no standard for the design of resilient distribution systems. Several elements of the strategy are well known: the hardening of distribution system components, the deployment

table 1. Typical and catastrophic outages.

Typical Outages	Catastrophic Outages
Most cases involve a single fault/failure.	Multiple or numerous components are damaged.
A small number of customers are affected.	A large number of customers are affected.
Power sources are available and accessible.	Power sources may not be available or accessible.
Transmission and distribution system facilities are available.	Transmission and distribution system facilities may be damaged or unavailable.
Repair and restoration are straightforward.	Repair and restoration are complex.

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